Precipitation Type Forecasting

A Top-Down Approach to Forecasting Precipitation Type

Operational Applications

National Weather Service
Louisville, KY

Top-Down Approach

- A way to assess what type of hydrometeors will form and track their trajectory to the surface to determine precip type
  - Will a cloud droplet or ice crystal form?
  - What will happen to particles as they descend toward ground?
  - What type of precip will occur at the surface?

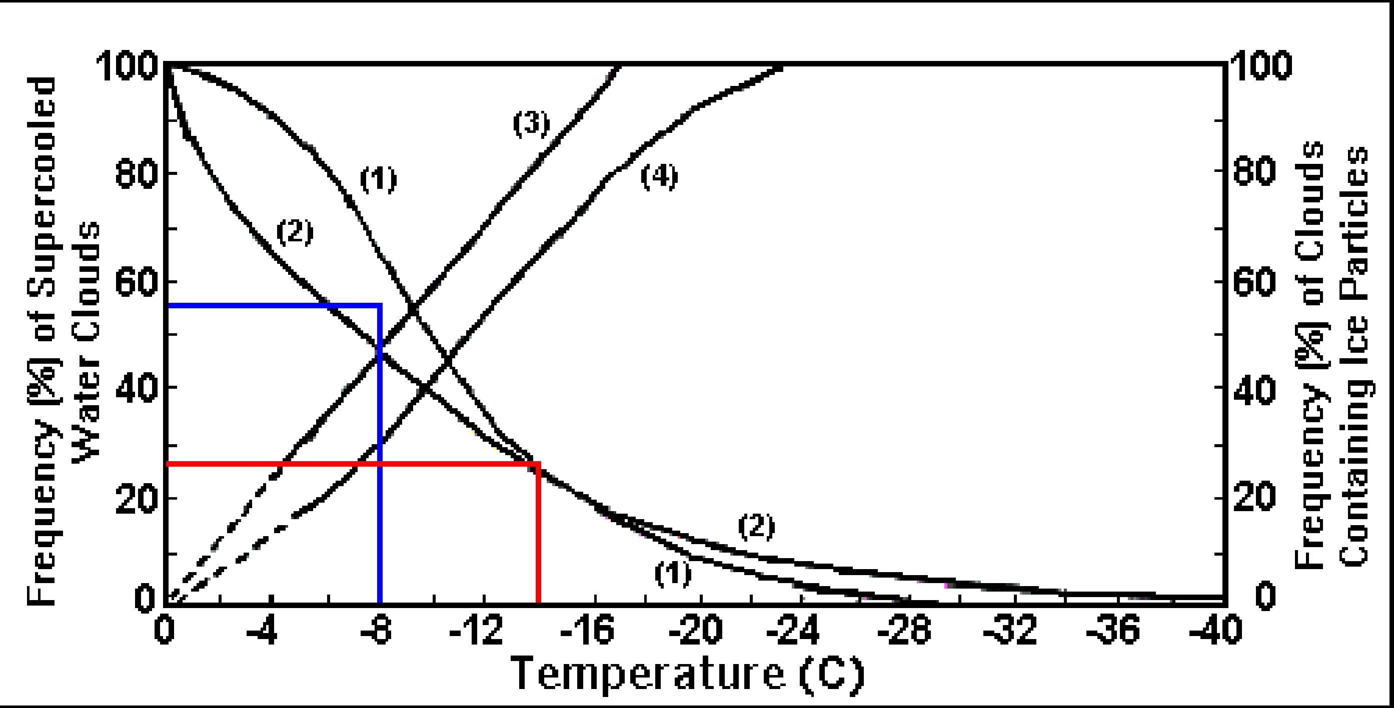
Types of Nuclei

- Cloud Condensation Nuclei (CCN): particles which allow cloud droplet or ice crystal growth on their surface
- Ice Nuclei (IN): CCNs which allow ice to grow on their surface
  - Most INs (kaolinite/clay, volcanic ash/dust, vermiculite) are activated at < -8 °C (especially -10 to -15 °C); silver iodide activated at about -4 °C
  - INs increase in number as temp decreases
  - -4 °C is *warmest* temp where any IN can be activated to allow ice to grow on its surface

Ice Crystal Formation on Ice Nuclei

- Heterogeneous nucleation and deposition: ice crystals form from these processes
  - Both processes most efficient with temps < -10 °C
- Ice multiplication: produces many crystals as supercooled water freezes on crystals, then splinter into more crystals
  - Most common at temps of 0 to -10 °C, *but* only after crystals which formed at < -10 °C fall into this warmer layer

Ice Versus Supercooled Water Clouds



Frequency of supercooled clouds and clouds containing ice crystals. Curves 1 and 2 (3 and 4) pertain to the labeled y-axis at left (right).

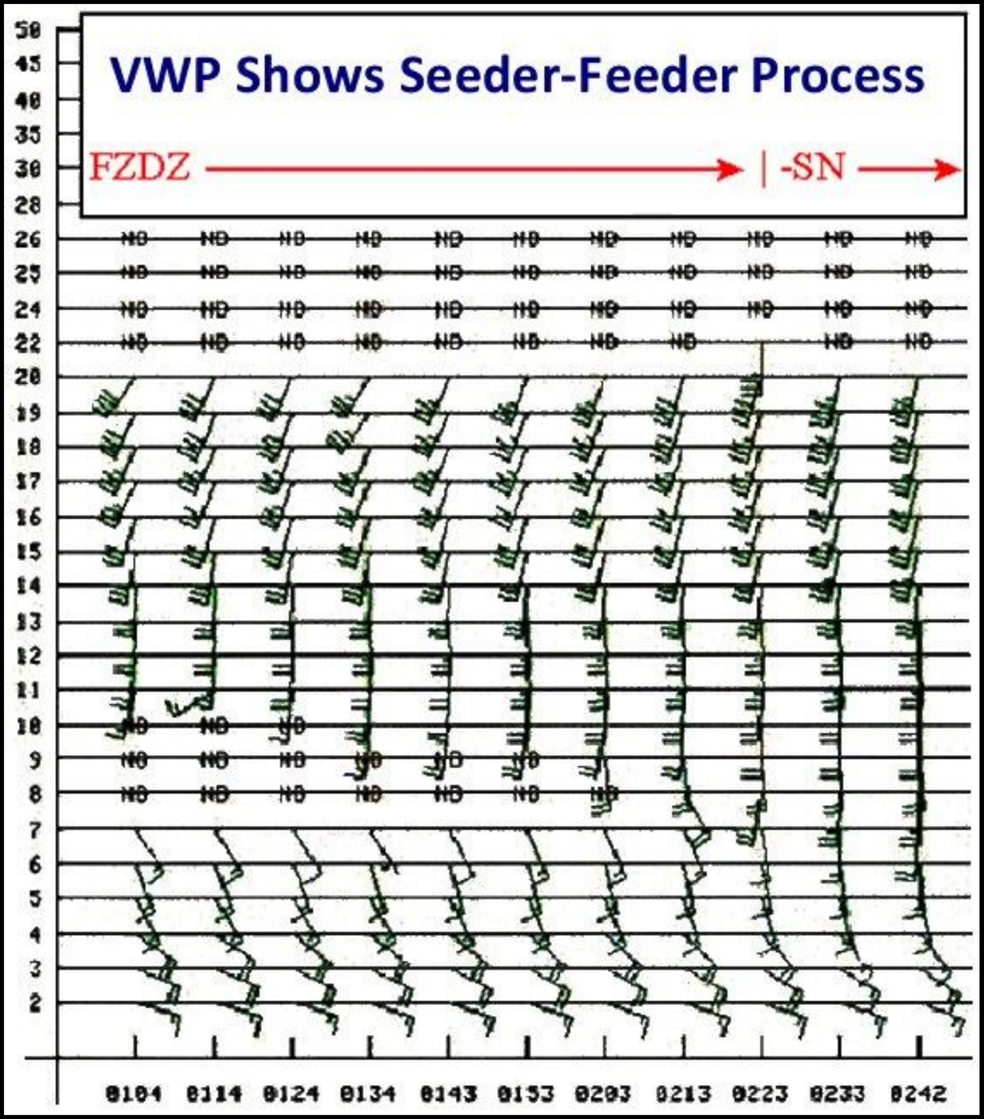
Microphysics Summary

- Research suggests:
  - -04 °C: Little of no ice in clouds, only supercooled droplets
  - -10 °C: 60% chance of ice in cloud: approximate cutoff temp
  - -12 °C: 70% chance of ice in cloud: key temp
  - -15 °C: 90% chance of ice in cloud
  - Over 50% of clouds contained all supercooled water and little or no ice if temps were > -10 °C
  - Most snow events associated with min cloud temps < -10 °C
  - If cloud (saturated layer) temps are > -6 °C, then only freezing rain (ZR), freezing drizzle (ZL), or rain (R) are most likely surface precip type

Seeder-Feeder Mechanism

- A non-saturated (cloud free) layer exists between upper and lower saturated layers (cloud decks)
- Crystals fall from an upper layer ice cloud (< -10 °C) into a lower supercooled liquid cloud (> -6 °C) resulting in lower cloud glaciating
- Maximum separation for seeder-feeder process is 3000-5000 ft; at >5000, ice will evaporate/sublimate before reaching feeder cloud
- Use vertical wind profiles (VWP) to help assess this process

Seeder-Feeder Mechanism



In this event, freezing drizzle changed to snow after warmer lower clouds were seeded by colder ice clouds above as evaporation led to saturation in the initially dry layer from about 7000-10000 ft.

Warm Layer Aloft

- Assuming a saturated warm layer above a cold (< 0 °C) boundary layer, what precip type is expected at surface?
  - Depends on warm layer temperature and depth, and whether ice is introduced from above into warm layer
  - Since a linear relationship usually exists between warm layer depth and max temp, it's easier to consider only temperatures

Warm Layer Maximum Temperature (or Tw)	Precipitation Type *with* ice introduced	Precipitation Type *without* ice introduced
< 1C	Snow	Freezing Drizzle/Rain**
1C to 3C	SN/PL Mix (1C) to All Sleet (2-3C)	Freezing Drizzle/Rain**
> 3C	Freezing Rain/Drizzle	Freezing Drizzle/Rain**

** Dependent on vertical motion

Warm Layer Aloft

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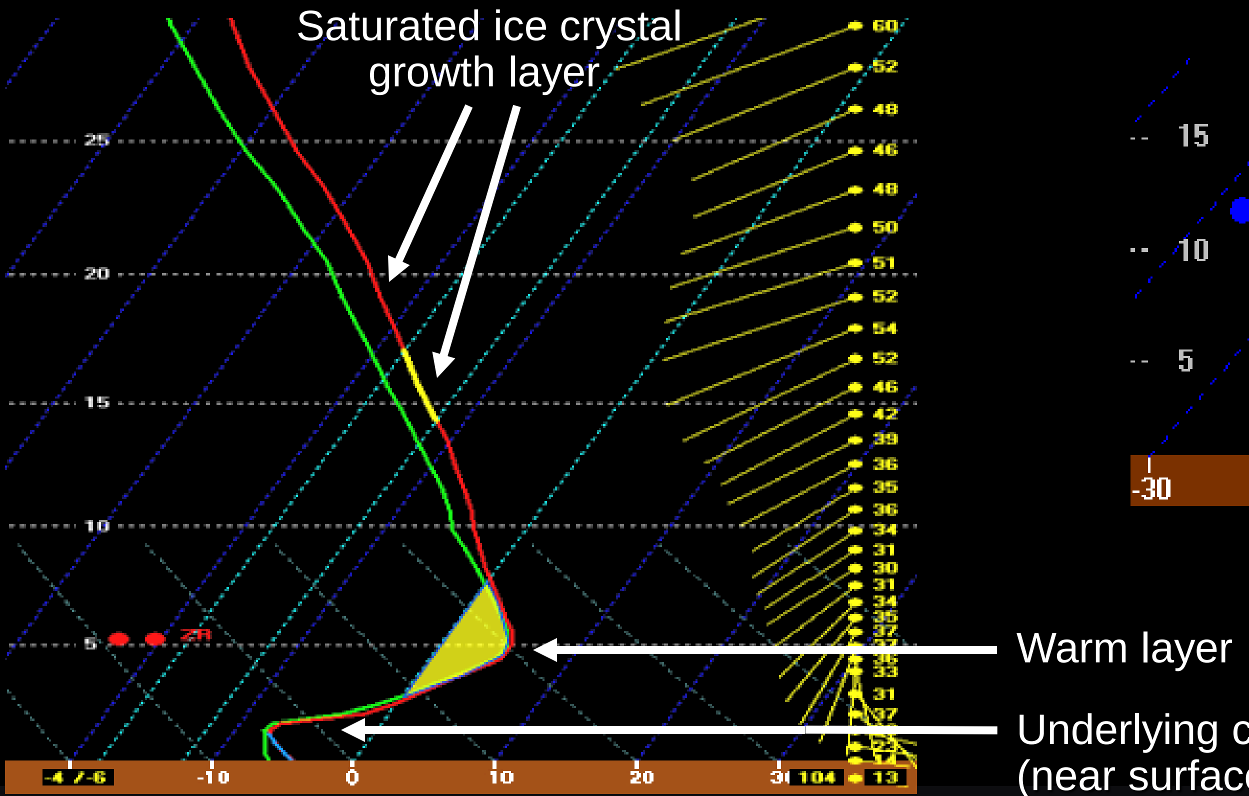

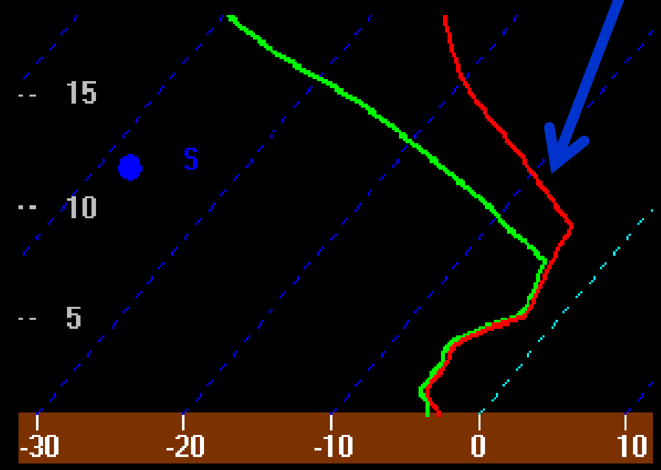

Warm Layer Aloft

Max temperature of warm layer (assumes a cold boundary layer)…

Warm Layer Maximum Temperature (or Tw)	Precipitation Type *with* ice introduced	Precipitation Type *without* ice introduced
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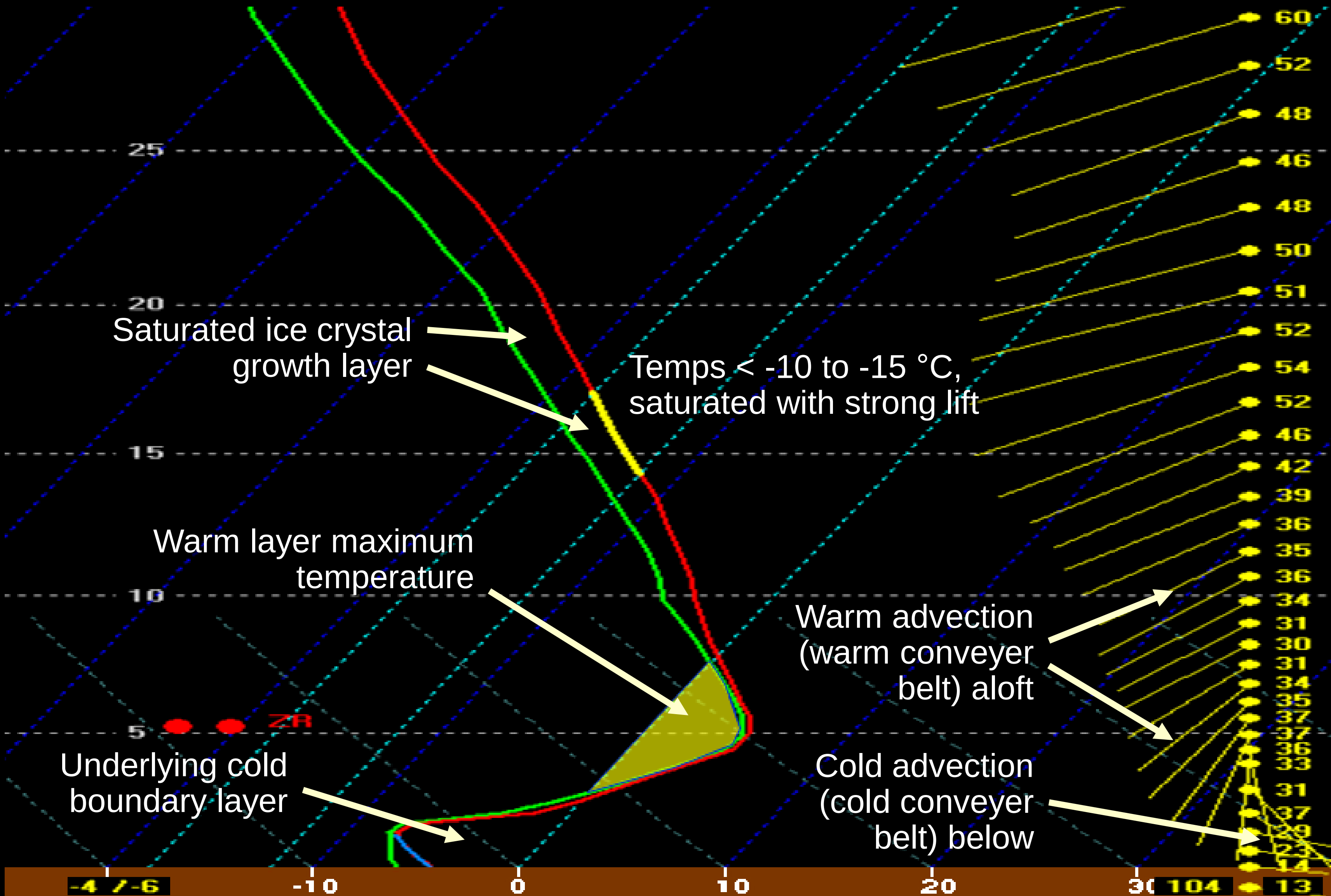
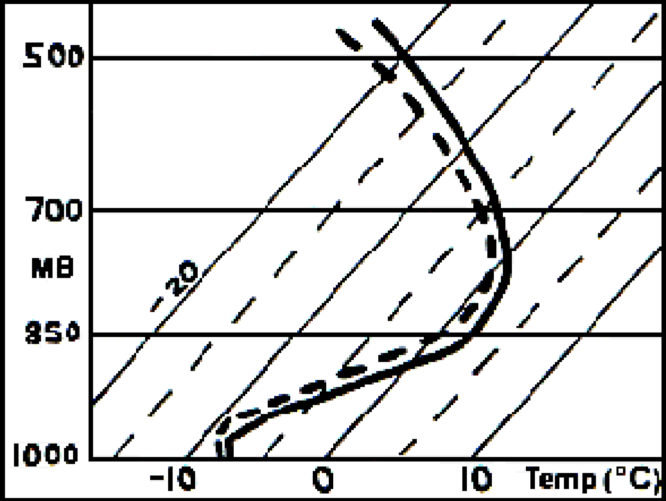
Cold Boundary Layer

- If boundary/surface layer < 0 °C, then frozen or freezing precip will occur, depending on temperatures aloft
- If wet bulb temperature (T_w) is > 33 °F for at least 1000 ft, then any ice likely will melt (rain/drizzle expected)
- Very cold temperatures (< -10 °C) can result in formation of ice crystals and possible snow within layer, even if warm layer exists aloft
- Cold temperatures < -6 °C AND deeper than 2500 ft in layer can cause refreezing of liquid drops from above into ice pellets before reaching surface
- Terrestrial temperatures: determines whether snow/ice will accumulate on ground/elevated surfaces

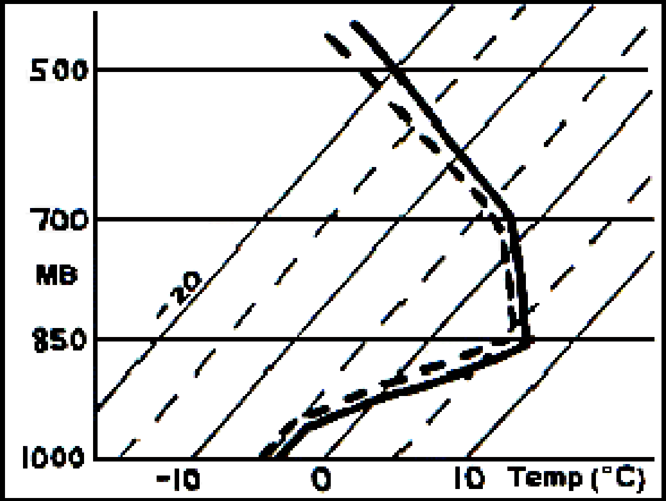
Top-Down Approach: 3 Important Layers



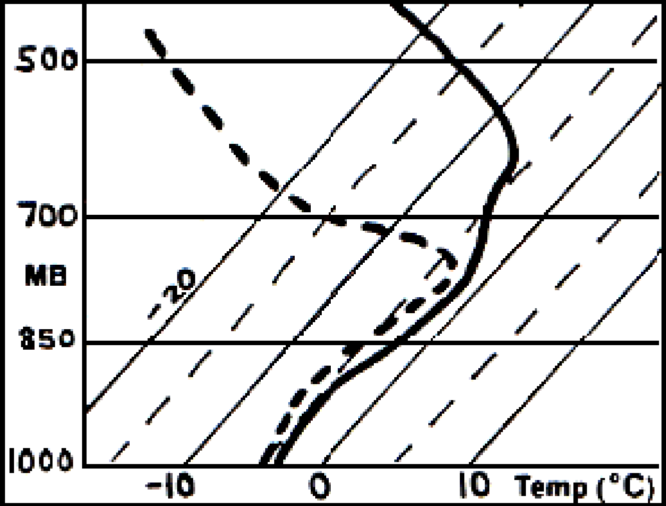
Sample Soundings



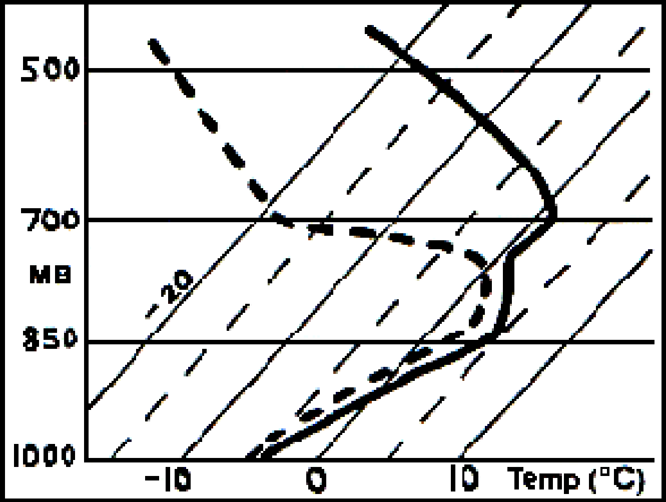
Mainly IP: Warm layer max temp +2.5 °C with very cold boundary layer



ZR: Warm layer max temp about +6 °C with cold boundary layer



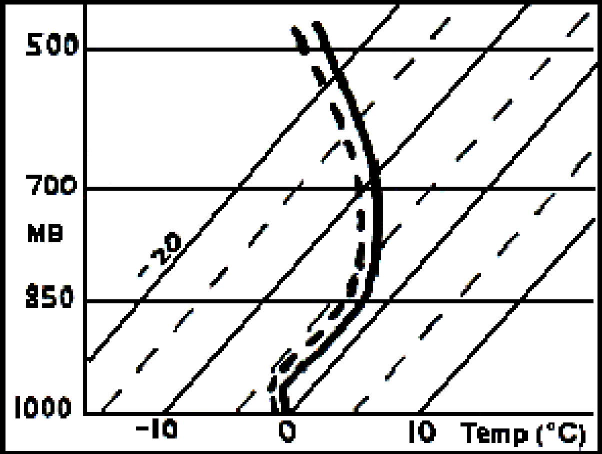
Mainly ZL: Min temp -3 to -5 °C; no ice crystal growth aloft



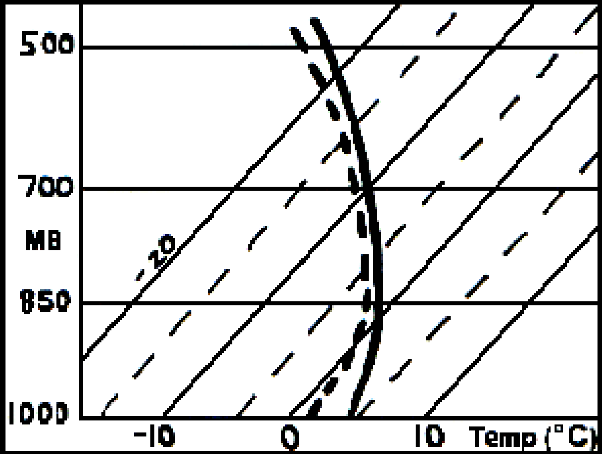
ZL: Warm layer max temp +5 °C; cold below; dry air aloft

No Warm Layer Aloft?

- No saturated warm layer aloft: boundary layer temperatures determine precip type (snow or rain)
- Optimal heavy snow sounding: T < 0 °C throughout deep-layered saturated air mass; isothermal layer above surface; moist-adiabatic lapse rates aloft; strong lift

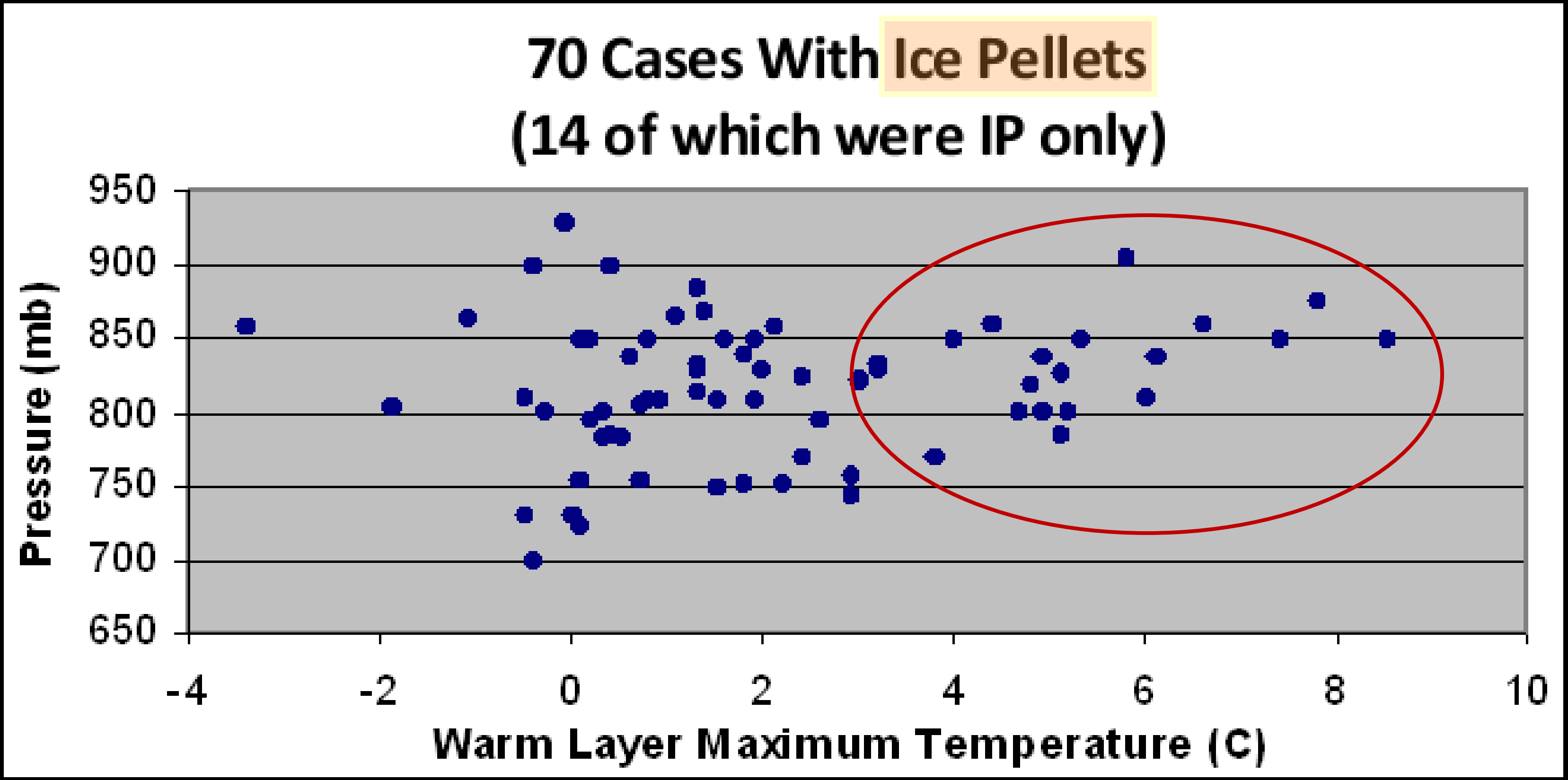


Heavy snow sounding given strong lift. Isothermal layer just below 0 °C then moist adiabatic above.



Snow will likely melt to rain (or rain-snow mix) in boundary layer due to temp, dewpoint, and wet bulb all above 0 °C.

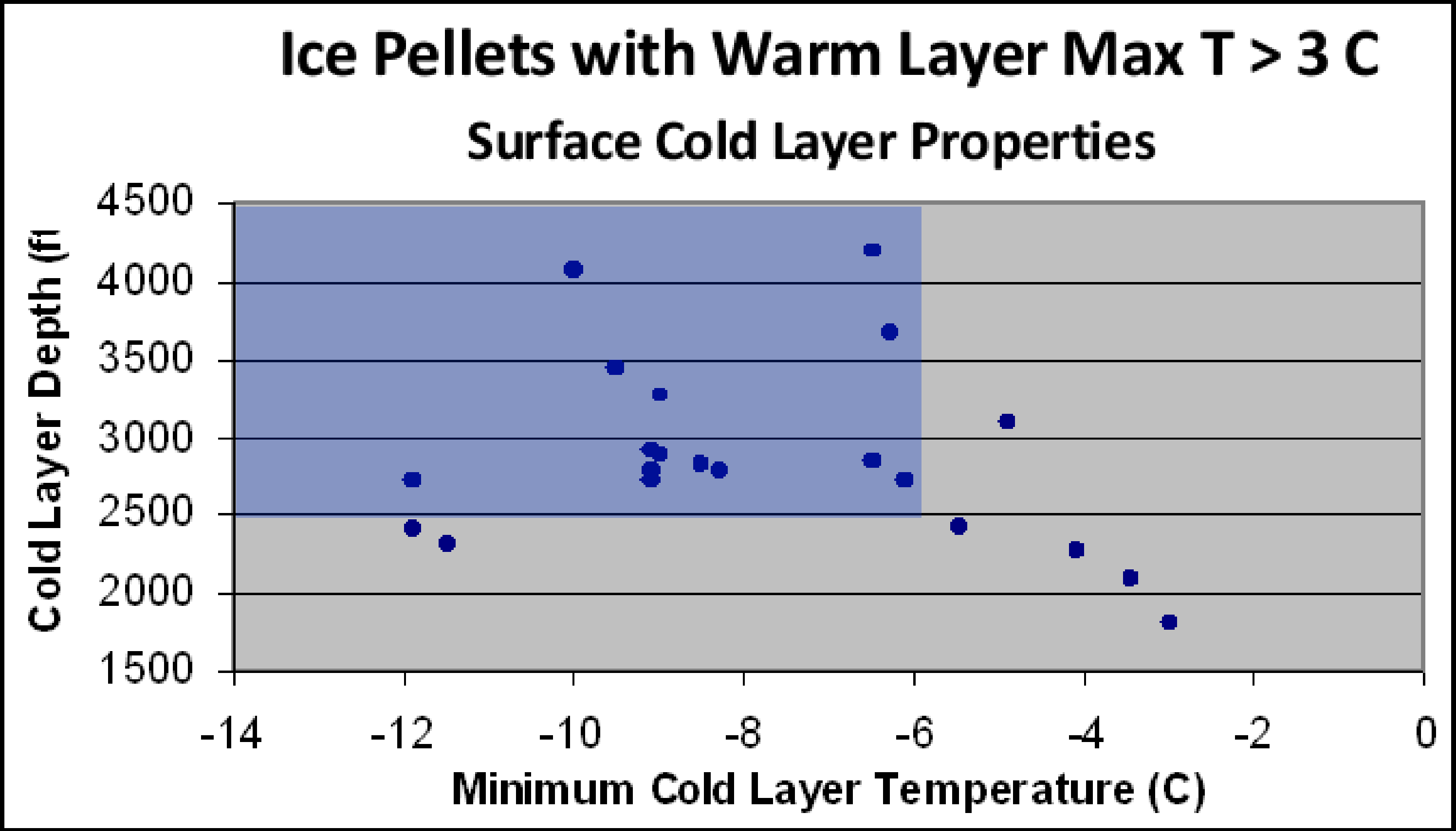
Freezing Precip Climatology Study



In this study, ice pellets (either IP only, or a ZR-IP mix) occurred at the surface with a warm layer maximum temperature > 3 °C (red circle).

How did IP occur? Temperatures > 3 °C normally mean ZR only.

Freezing Precip Climatology Study

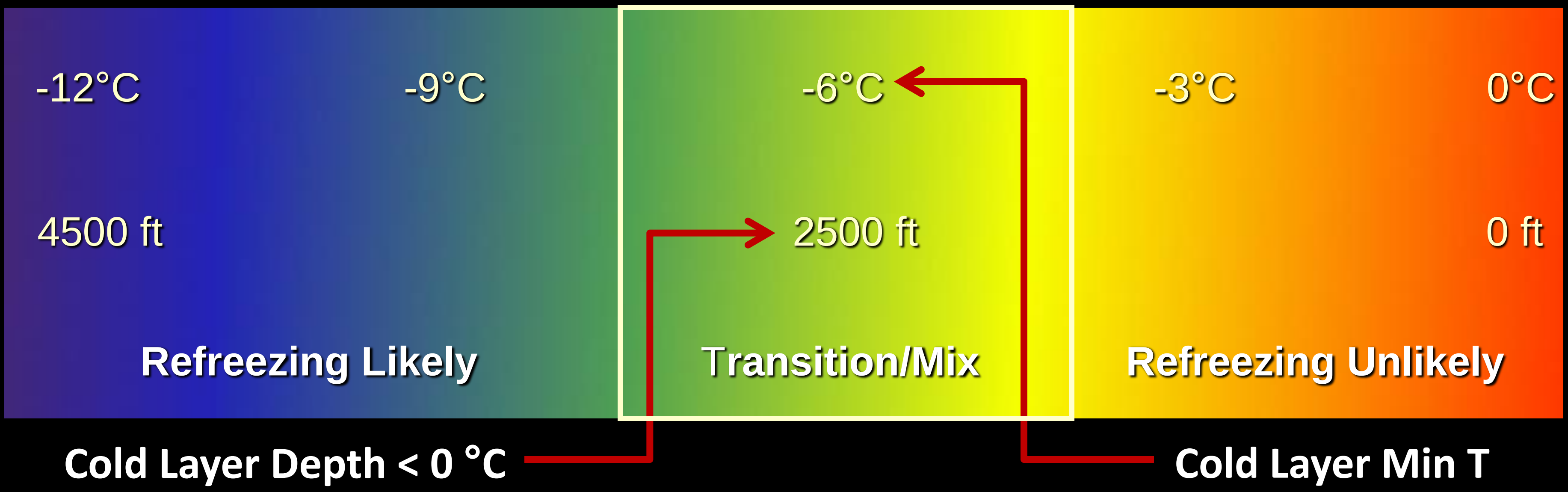


Refreezing Liquid to Ice Pellets in Cold Boundary Layer:

Key Cold Layer Properties:

750m (2500 ft) depth AND -6 °C or colder

Refreezing Liquid to Ice Pellets



Refreezing Liquid to Ice Pellets in Cold Boundary Layer:

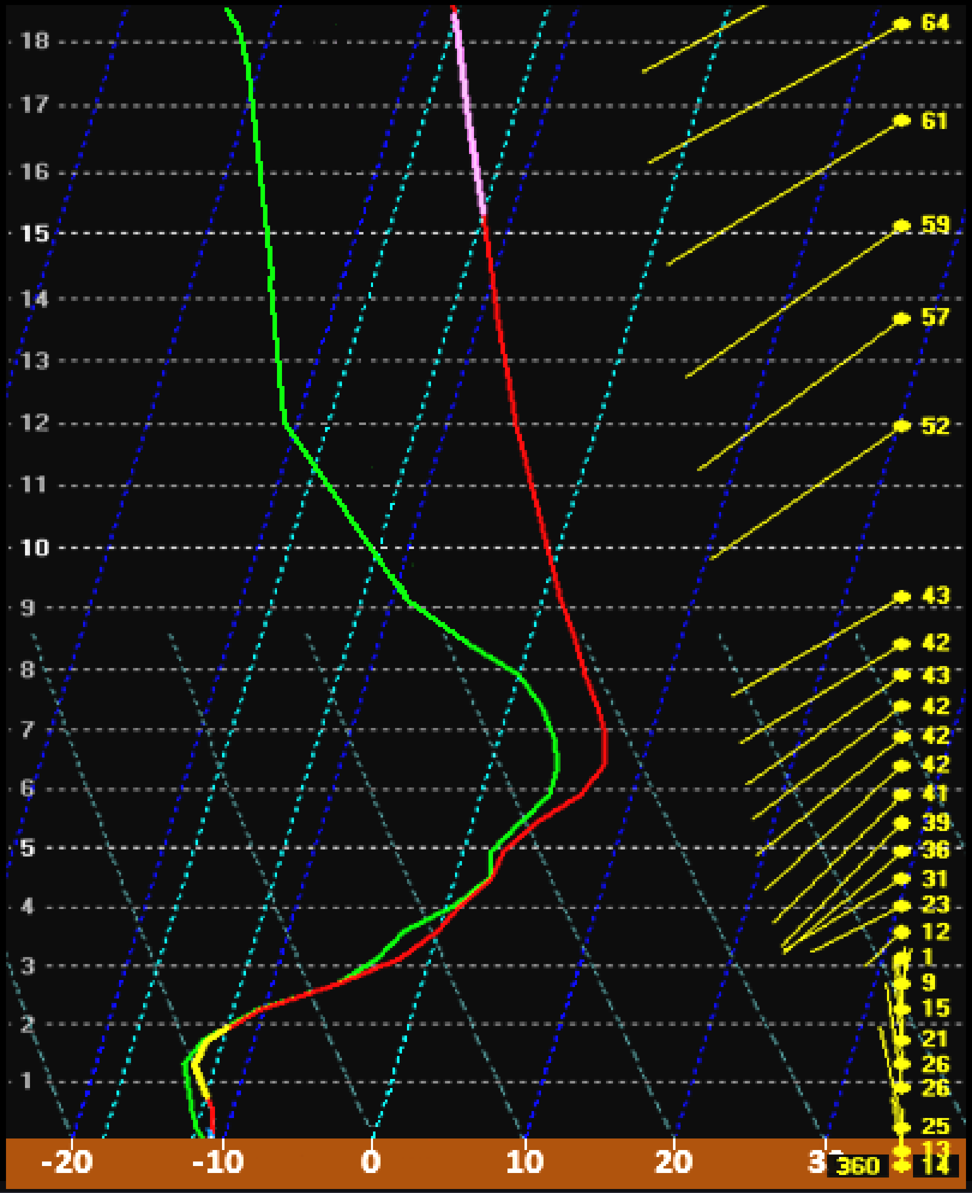
Key Cold Layer Properties:

750m (2500 ft) depth AND -6 °C or colder

Cold Boundary Layer Summary

- ICE/LIQUID mix incoming (partial melting in warm layer):
  - Freezing of particles to ice pellets if temps < 0 °C
- LIQUID incoming (full melting in warm layer):
  - Freezing of particles on ground or elevated surfaces (freezing rain/freezing drizzle) if temps < 0 °C
  - If temps colder than -6 °C for at least 750m (2500ft), liquid particles may re-freeze to ice pellets before reaching ground
- ICE NUCLEI activation?
  - If cold layer min temp is -10 °C or colder, there's an increased chance for ice nuclei activation in saturated layer resulting in snow, regardless of any warmer layer aloft
- SIZE: Small drops able to refreeze quicker than larger ones; use radar reflectivity (dBZ values) to help assess particle size

Sounding Assessment: Precip Type?



QUIZ QUESTION:

Based on this sounding, what precip type(s), if any, would you expect at the surface? Why?

ANSWER:

Light sleet and snow mixed. It is dry aloft, so there are no ice crystals forming. There is some liquid in the moist layer above 0 C (4-6 kft), which should freeze to light sleet in the deep cold lower layer. Also, ice crystals could form in this very cold lower layer resulting in snow showers.

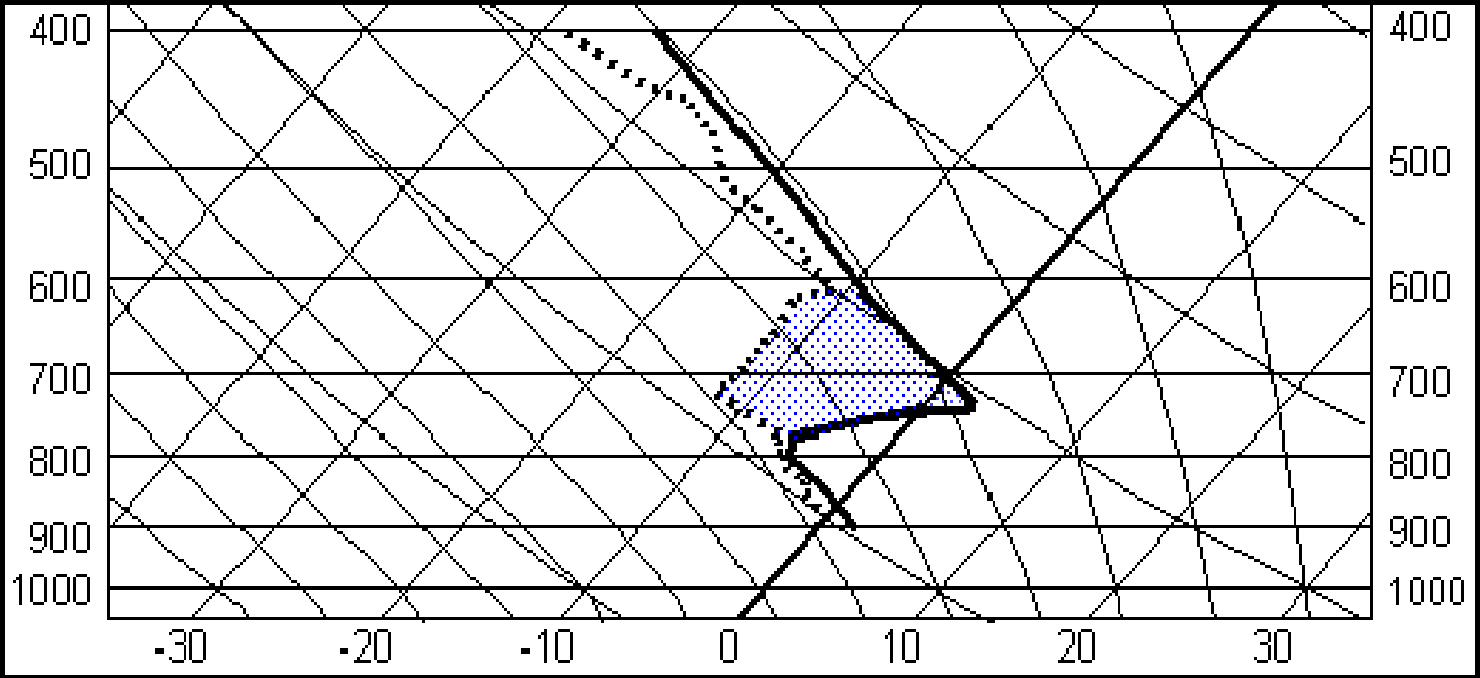
Factors Affecting Precip Type

- Adiabatic effects
  - Thermal advection: warm advection occurring, but ascent produces pseudo-adiabatic cooling; if ascent is strong (frontogenetical forcing), it can counteract warm advection resulting in little or no net warming or even cooling (models can show this); synoptic scale advections are important when not overwhelmed by diabatic effects
- Forcing mechanisms
  - Jet streak circulations: complements/intensifies isentropic lift in right entrance and left exit regions of jet streaks
  - Frontogenesis: strengthens mesoscale lift resulting in banded precip, especially near elevated baroclinic zones; occurs near jet entrances

Factors Affecting Precip Type

- Diabatic effects
  - *Evaporation:* as hydrometeors fall into an unsaturated layer, evaporation causes removal of heat from air; result is a temp decrease and dewpoint increase as both approach *wet bulb temp* (Tw; key parameter); cooling can be several degrees resulting in a possible precip phase change; most pronounced at onset of event
  - *Melting:* causes cooling; usually not that significant unless advection is weak, precip type is borderline, or if a large amount of melting occurs, such as elevated convection feeding a warm layer below; can be important near precip phase transition zones
  - *Convection:* can change vertical temp profile and affect precip type

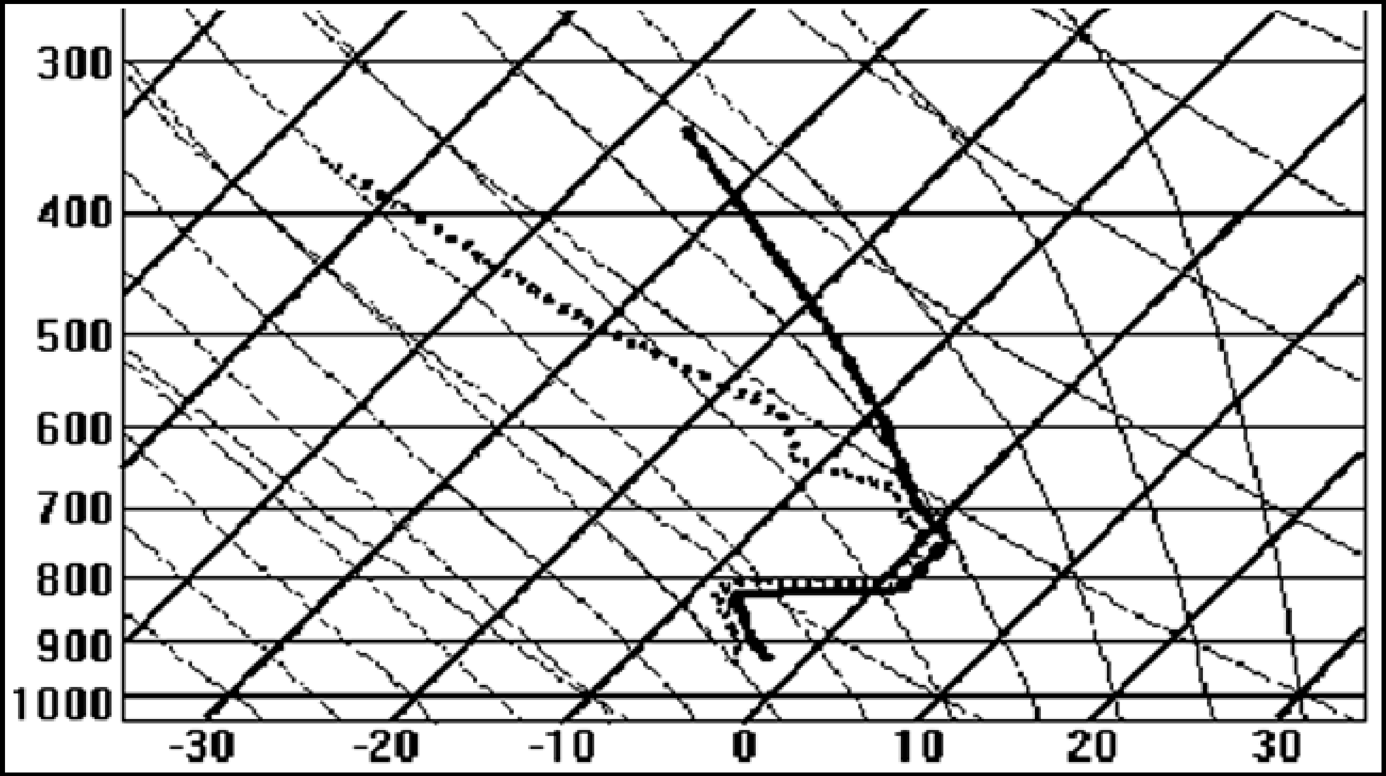
Operational Application



Q: What effect will the dry layer aloft have on temp structure and precip type as hydrometeors from above fall into it?

A: EVAPORATION will cool the small above freezing layer aloft to the wet bulb temp below freezing, which will affect precip type.

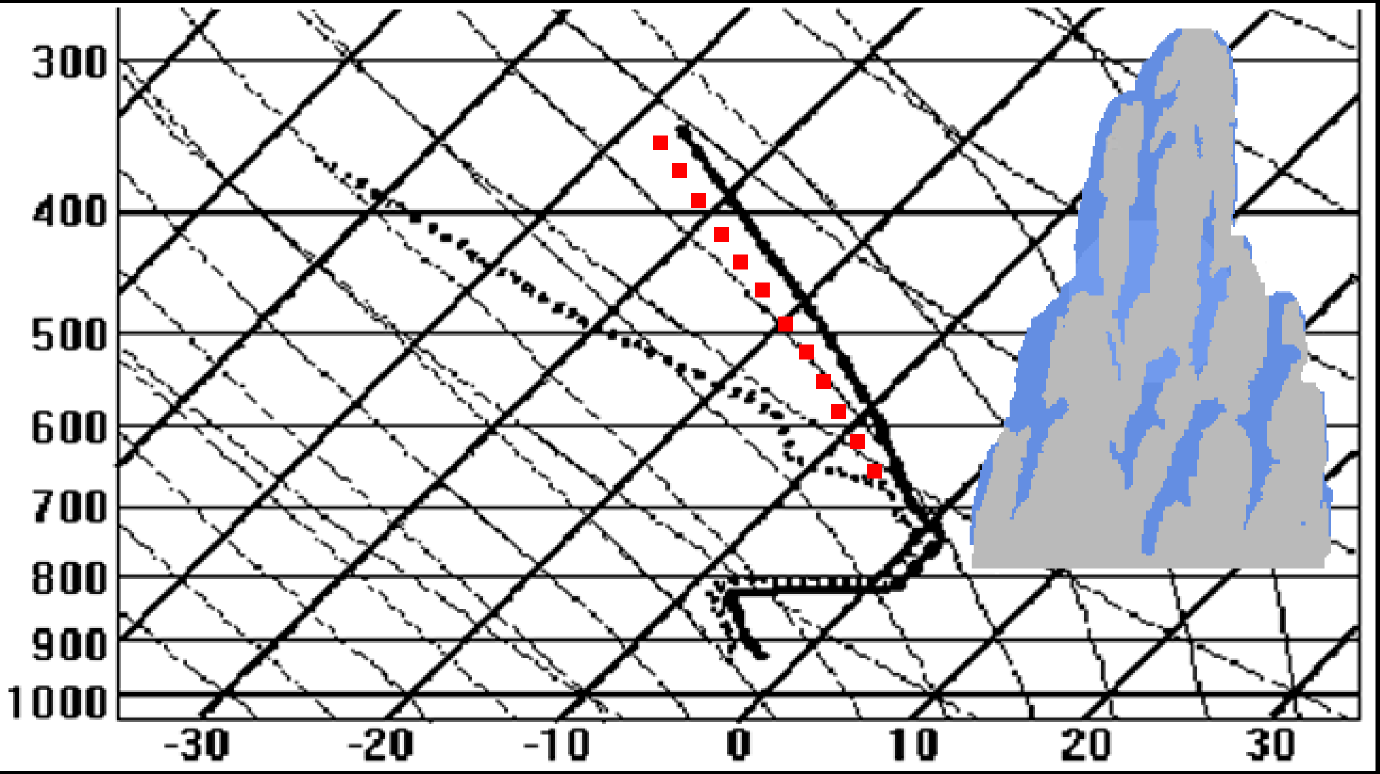
Operational Application



Q: What precip type would you expect in this sounding? Why?

A: Sounding is unsaturated aloft at -10 to -15 °C, so light freezing rain/drizzle or sleet/graupel is expected; possibly some snowflakes if they can initiate within the cold boundary layer since min temps are about -8 °C.

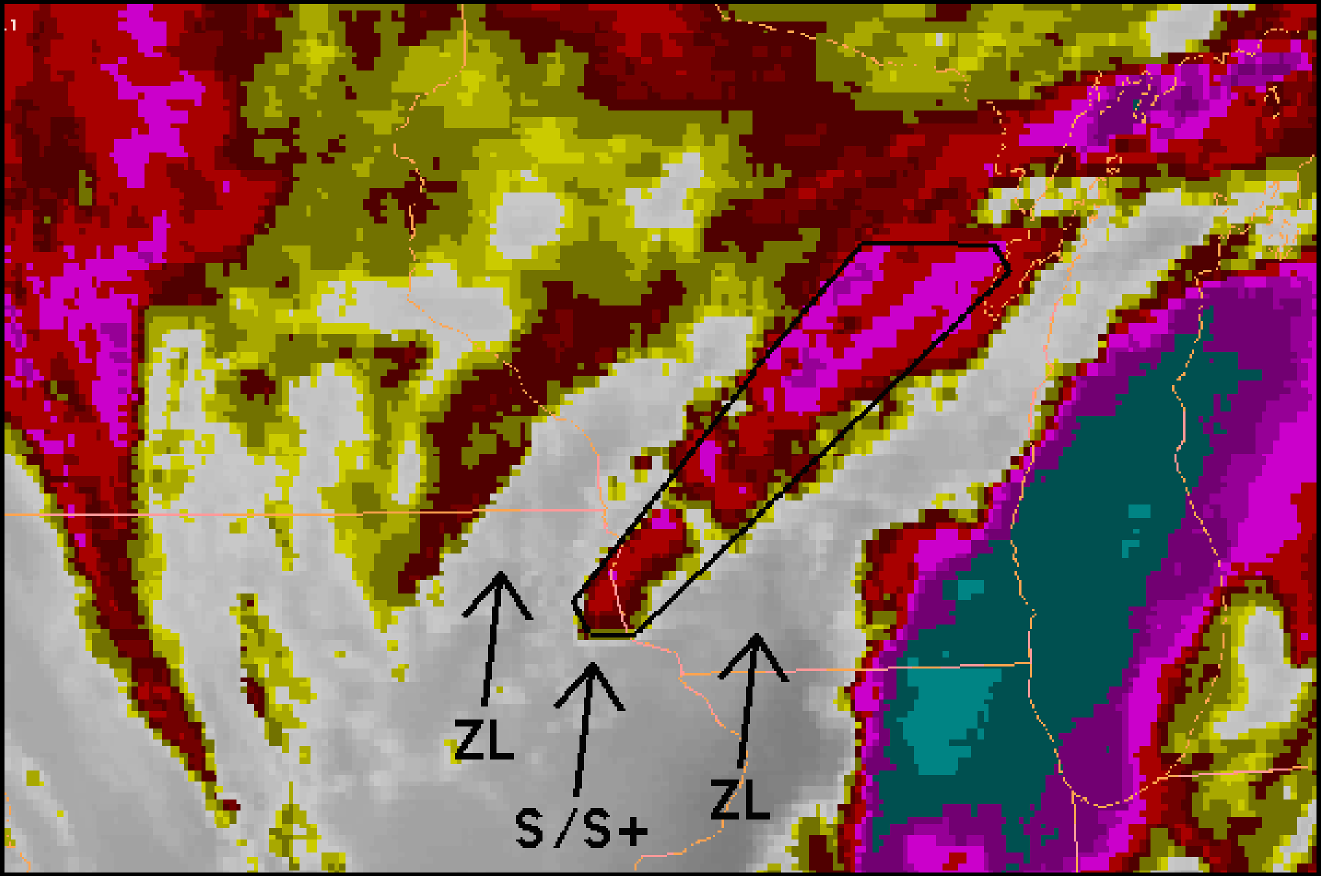
Operational Application



Q: If elevated convection develops in location of original sounding (on previous slide), what effect might it have on the sounding profile and precip type?

A: CONVECTION introduces strong lift and saturation aloft in -10 to -15 °C layer. Thus, efficient ice crystal production can occur, resulting in a precip change from light freezing rain/drizzle potentially to heavy snow.

Operational Application



In this storm, freezing drizzle was falling in the unenhanced region, with a band of convection and heavy snow in the middle. This is a mesoscale forecast problem, which can be addressed by enhanced short term updates.

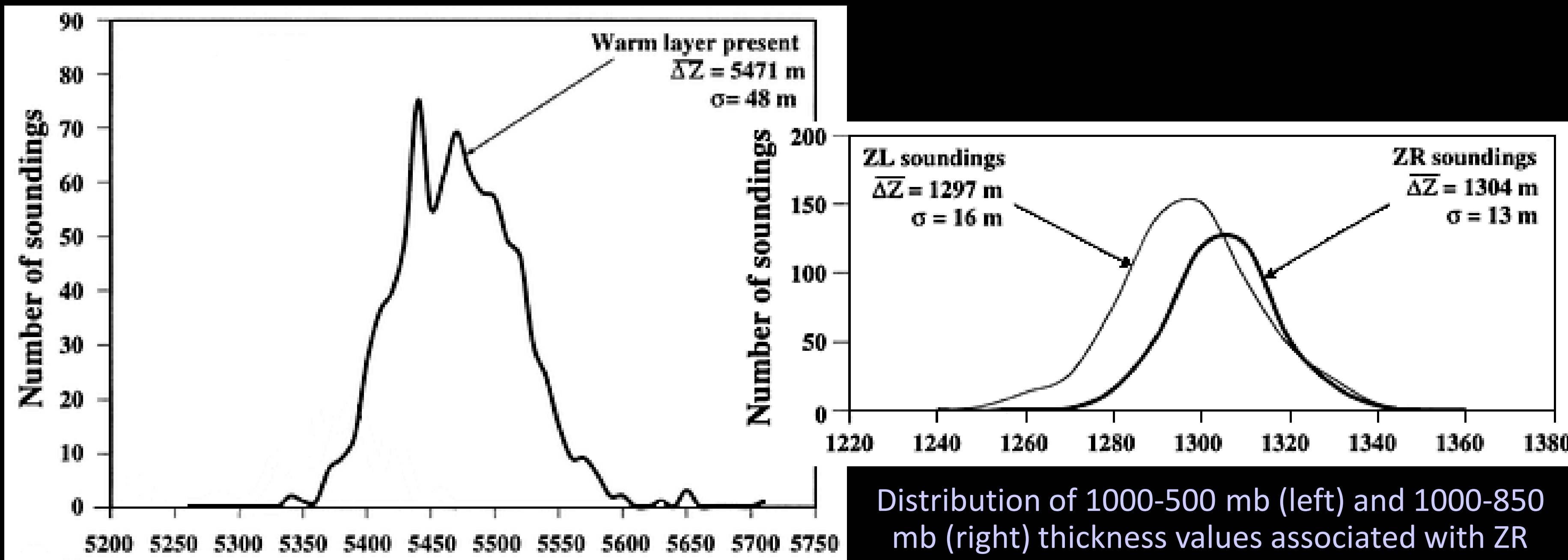
Precipitation Type and Intensity

- Light liquid or freezing rain/drizzle can change to sleet/snow whenever the intensity of precip increases (i.e., stronger vertical motion) due to one or more of these effects of strong ascent:
  - Increased (pseudo) adiabatic cooling
  - Increased cloud depth (colder cloud tops) resulting in ice crystal processes aloft (potential seeder-feeder)
  - Larger snowflakes, which take longer to melt
  - Increased cooling due to melting with heavier precip
- Watch out for elevated convection! It can change ZR/ZL to heavy snow quickly
- Once ascent/precip rates decrease, precip may change back to liquid or freezing rain/drizzle

Thickness Considerations

- Critical thickness layer values are available as a rough first guess to assess mean layer temp and precip type:
  - 1000-500 mb: 5400 m
  - 1000-700 mb: 2840 m
  - 1000-850 mb: 1300 m
  - 850-700 mb: 1540 m
- However, thicknesses do not fully account for temps and depths of warm and cold layers in a sounding or the degree and level of air mass saturation

Freezing Precip Climatology Study



Distribution of 1000-500 mb (left) and 1000-850 mb (right) thickness values associated with ZR events in study.

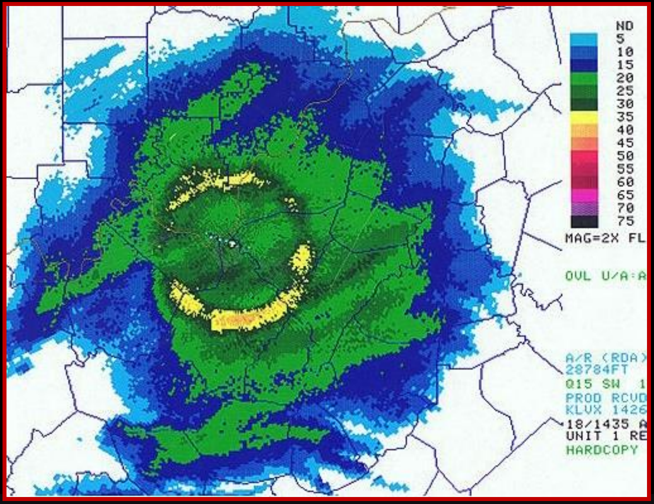
Conclusion from Study:

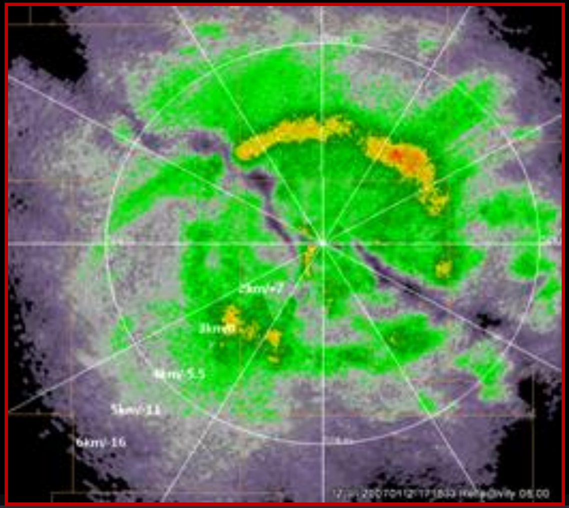
"A wide range of both 1000–500 mb layer thickness and 1000–850 mb layer thickness values were found during freezing precipitation events. This spread in values and the fact that freezing precipitation zones are typically narrow indicate that layer thickness is generally a poor predictor of the position and width of freezing precipitation zones."

Always analyze soundings instead of thickness to determine final precip type

Radar Bright Banding

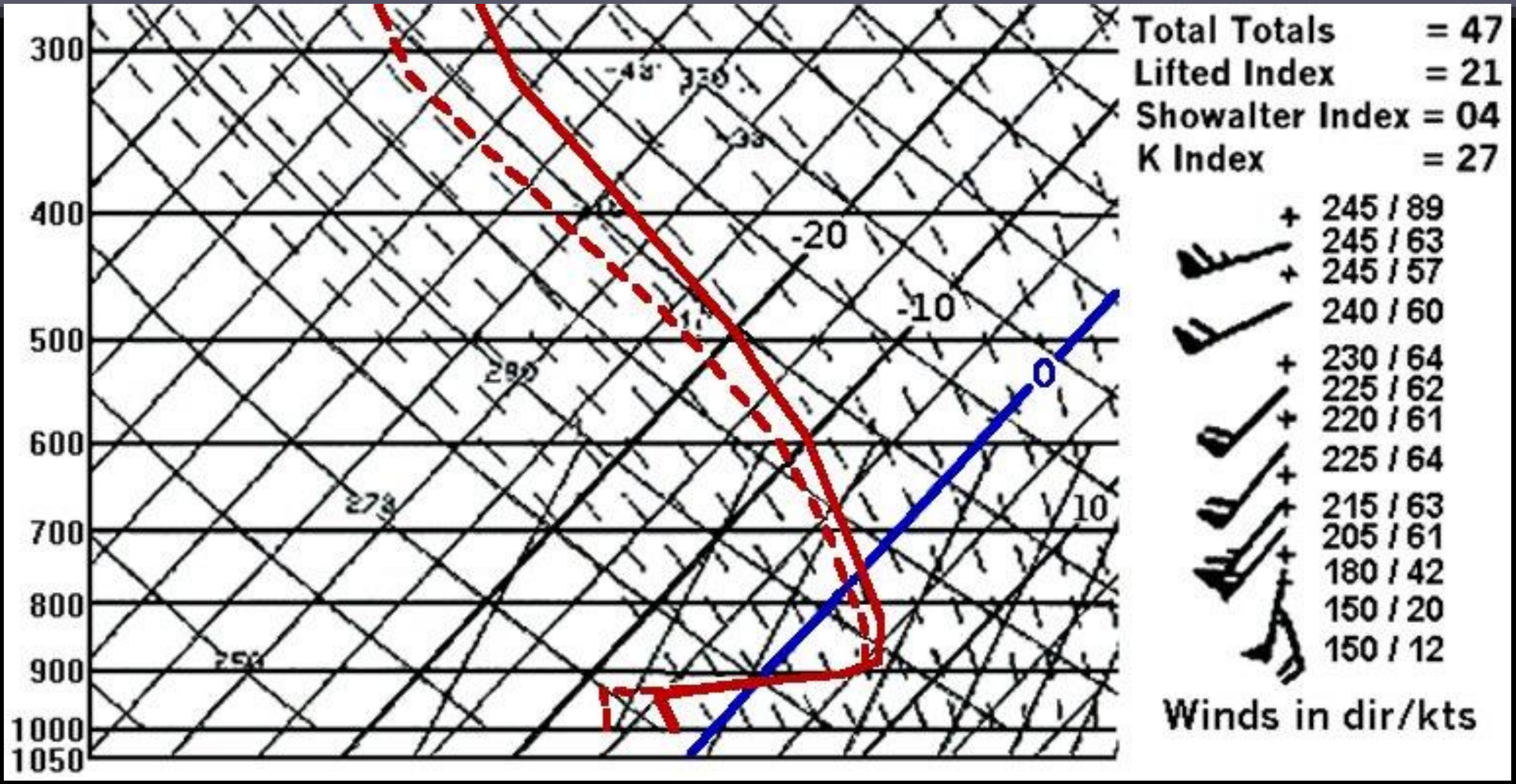
- Represents the melting level where crystals from above are beginning to melt into warmer air below. The liquid coated crystals become more reflective producing a circular band of higher reflectivity values
- Bright banding on radar means a change of phase is occurring!
- Short term forecasting: Monitor how the band expands (melting level rising) or contracts (melting layer lowering, i.e., snow getting closer to making it to the surface)





Summary: Operational Considerations

- What is the vertical temp and moisture profile that will affect precip?
- Is moisture/lift present in ice crystal (dendritic) growth zone (< -10 °C)?
- Will seeder-feeder processes occur?
- Is there a dry layer where evaporation will occur?
- What is the temp and depth of any warm layer?
- What is the temp, depth, and wet bulb in the boundary layer?
- Is elevated convection possible; what effect will it have?
- How will synoptic advections and lift affect temps?
- Will surface (terrestrial) temps allow for snow/ice accumulation?
- Are models and model soundings correct? What are their biases?
- What precip type do you expect at the surface, and how may it change?



Put it all together. Use the sounding to answer the summary questions.

- What is vertical temp and moisture profile that will affect precip?
- Is moisture and lift present in ice crystal growth zone (< -10 °C)?
- Will seeder-feeder processes occur?
- Is there a dry layer where evaporation will occur?
- What is temp and depth of any warm layer?
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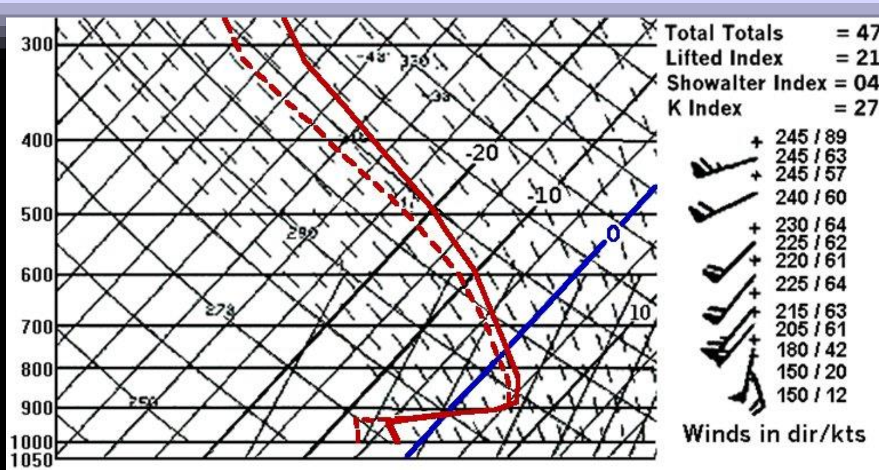
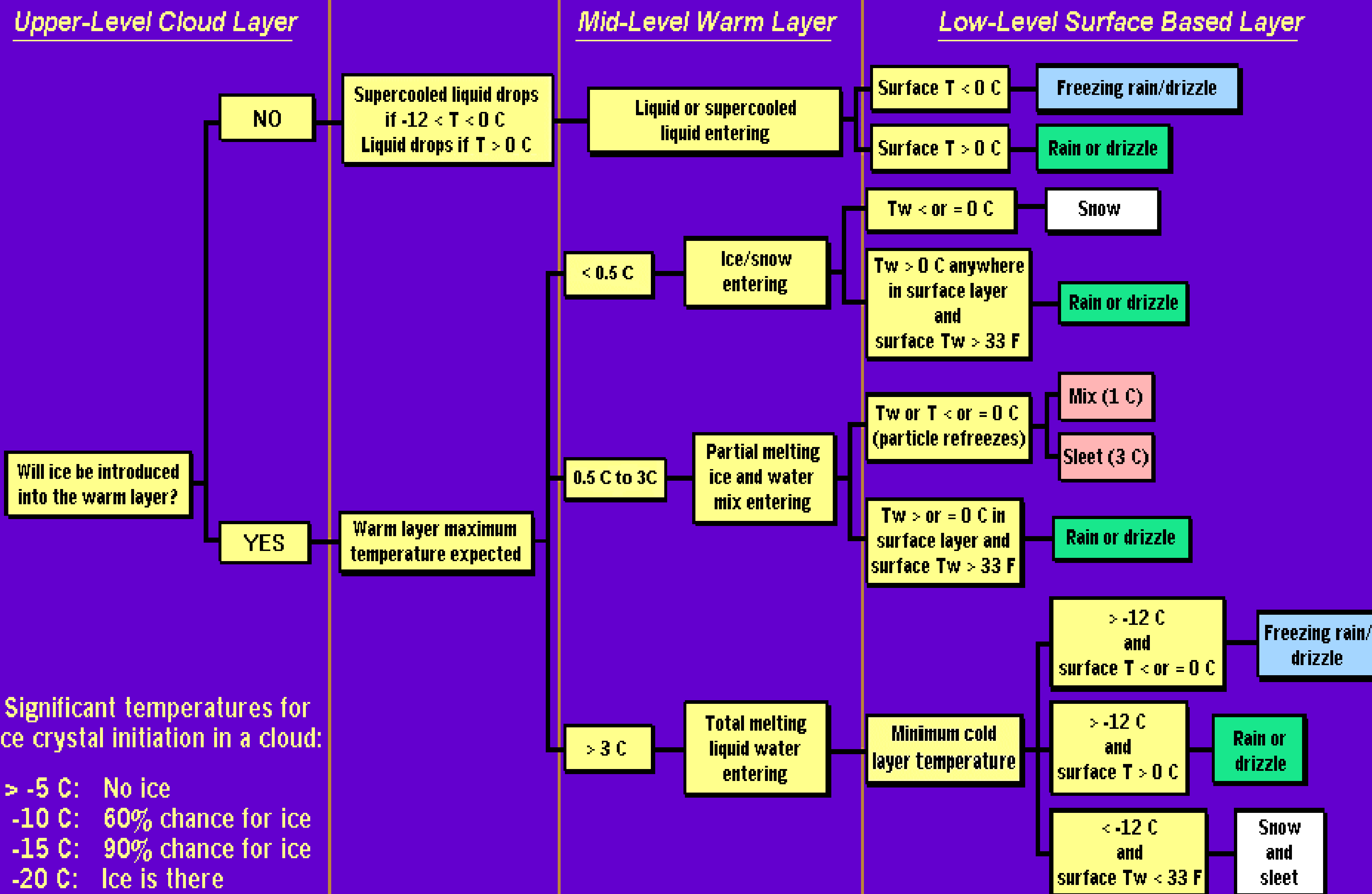


Answers

- What is vertical temp and moisture profile that will affect precip? Deep saturation; cold boundary layer, warm layer aloft, and moist adiabatic lapse rates above.
- Is moisture and lift present in ice crystal growth zone (< -10 °C)? Yes. Deep saturation for crystal production.
- Will seeder-feeder processes occur? No dry air in sounding, so process unlikely now (perhaps at event onset).
- Is there a dry layer where evaporation will occur? No. This process may have had an effect at event onset.
- What is temp and depth of any warm layer? Depth >100 mb with max temp +5 °C, warm/deep enough for complete melting of crystals within layer.
- What is temp and wet bulb in boundary layer? Min T and Tw around -5 °C, cold enough for surface freezing (ZR), but not cold/deep enough to refreeze liquid to ice pellets (IP) or for crystal production in boundary layer.
- Is elevated convection possible? Yes, slantwise convection. Note moist adiabatic lapse rates aloft and Totals in upper 40s. Higher instability was present upstream on nose of strong low-level jet advecting into region. Strong frontogenetical forcing also aided in development of elevated banding of very heavy precip.
- How will synoptic advections and lift affect temps? Can't tell from sounding, but warm advection and strong synoptic/mesoscale lift were present; temps didn't warm despite advection indicating heavy precip potential.
- Will surface temps allow for snow/ice accumulation? Yes.
- What precip type do you expect at surface? At this time, freezing rain was occurring. But, strong adiabatic cooling (due to strong lift) and melting (due to elevated convection) led to rapid erosion of ambient warm layer and development of isothermal layer just below 0 °C. This resulted in precip change to heavy snow. This is Paducah, KY's sounding at 00 UTC 17 Jan 1994, a storm that caused 1-2 feet of snow in parts of northern KY.

Top-Down Precipitation Type Flow Chart



Significant temperatures for ice crystal initiation in a cloud:

> -5 C: No ice
-10 C: 60% chance for ice
-15 C: 90% chance for ice
-20 C: Ice is there